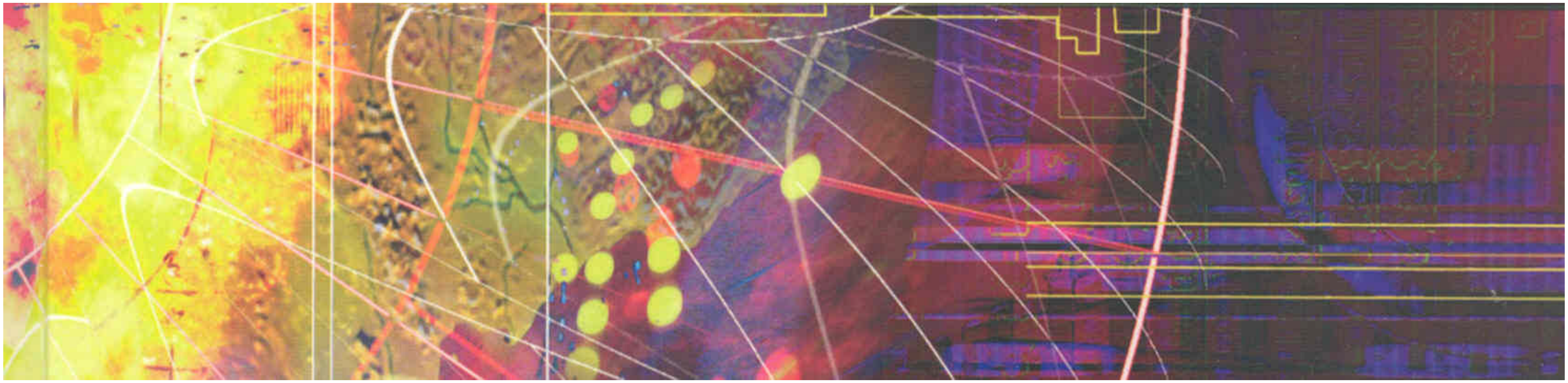


EE303 Lesson 12: Superheterodyne Receivers

Receiver characteristics

- What are the functions of a receiver?

WETA-FM 90.9 MHz
Transmitted power 75,000 W

Received power
~0.00000000000001 W

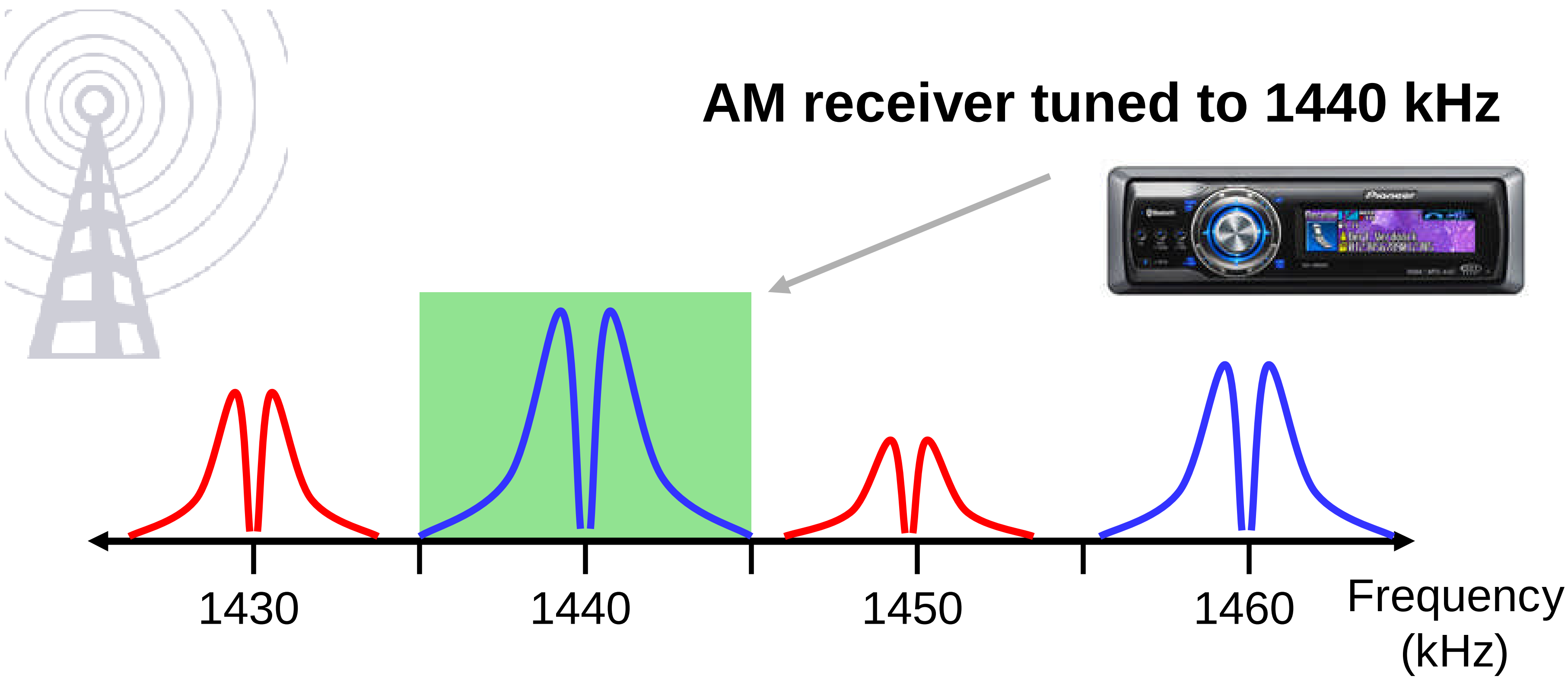
Receiver characteristics

- First, it must be able be able to select the desired signal from the thousands of other signals in the spectrum.
- Second, it must provide amplification to recover the original modulating signal from a very weak received signal.

Receiver

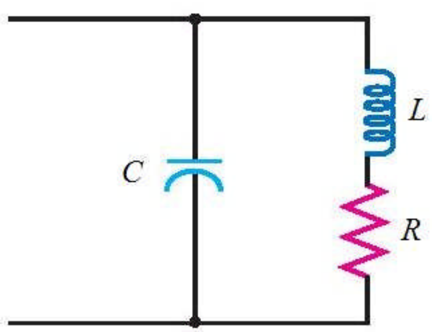
Selectivity

- **Selectivity** refers to the ability of a receiver to differentiate the desired signal and other undesired frequencies.



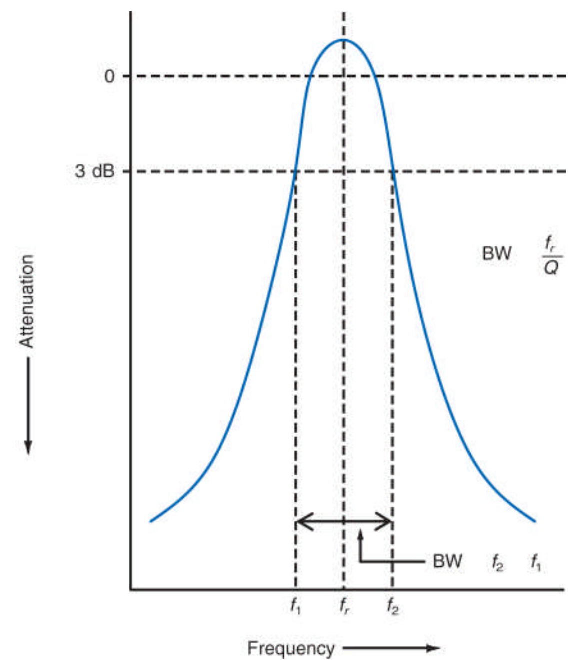
Selectivity

- Initial selectivity is obtained using *LC* tuned circuits like the parallel resonant circuit depicted below.
  - Note: We did not previously analyze this circuit, but the governing equations for f_r and Q are the same as the series *RLC* circuit.



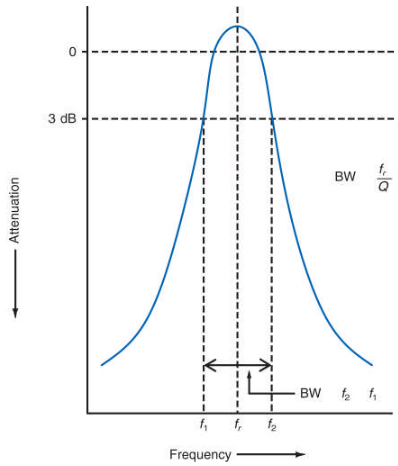
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$Q = \frac{f_r}{\text{BW}} = \frac{X_L}{R} = \frac{2\pi f_r L}{R}$$

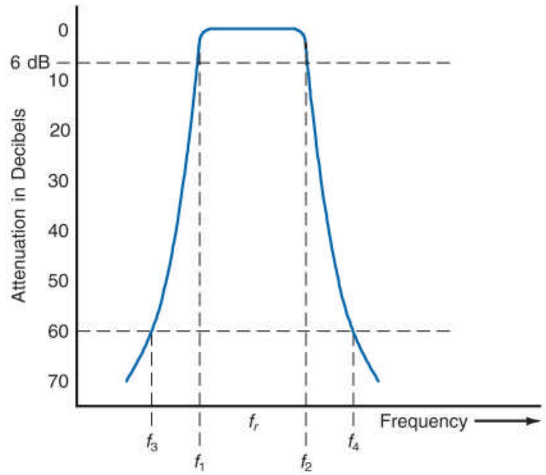


Selectivity

- The filter characteristic of an *RLC* circuit does not provide ideal selectivity.
- An ideal filter would provide
  - Constant gain across the passband.
  - Near vertical sides to attenuate everything outside the pass band.



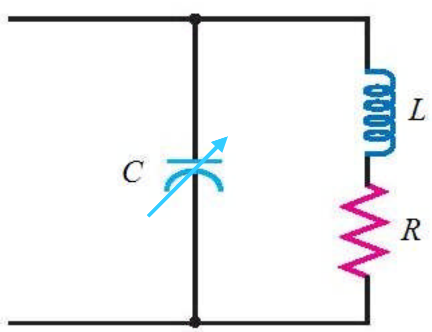
RLC response curve

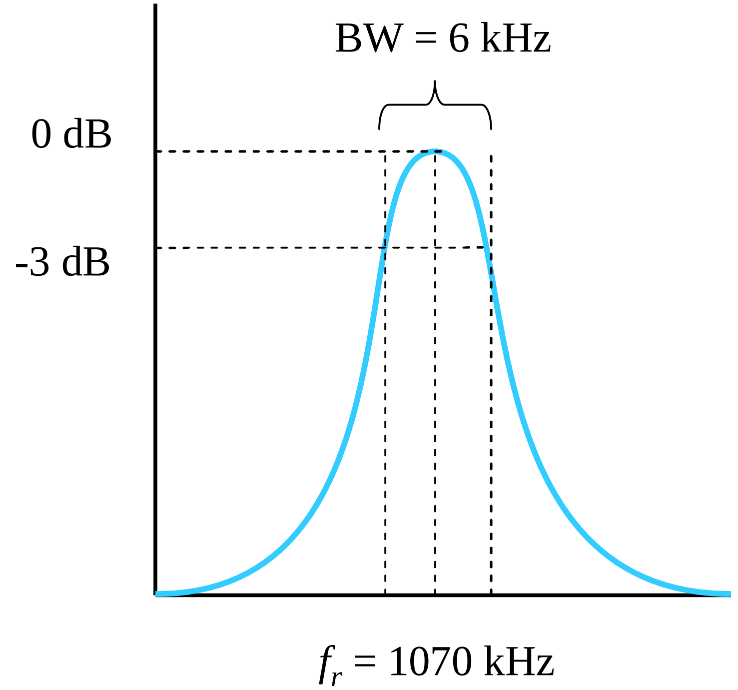


Practical response curve

Example Problem 1

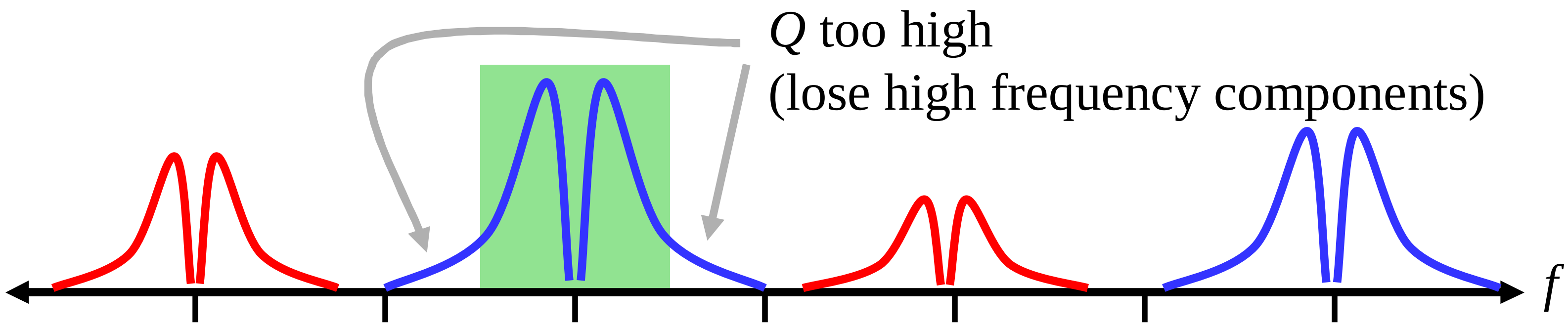
Consider simple AM radio receiver. Tuning this radio is accomplished by adjusting a variable capacitor C. Say we want tune this radio for middle of the AM dial (1070 kHz). Also, we desire a 3-dB bandwidth of 6 kHz. If $R = 10\ \Omega$, determine the require values of L and C.



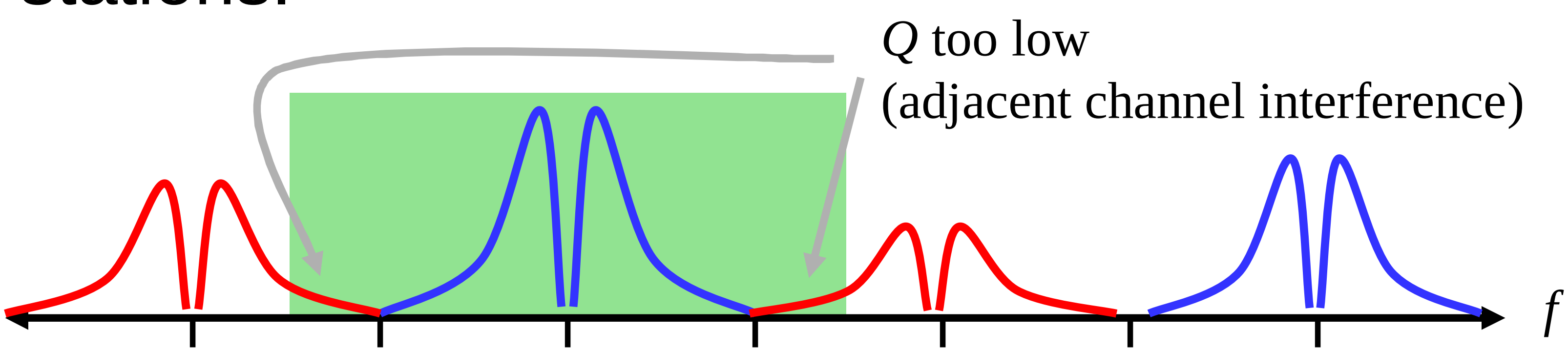


Selectivity Problems

- Overly selective receiver results in a loss of fidelity due to clipping of upper frequencies.

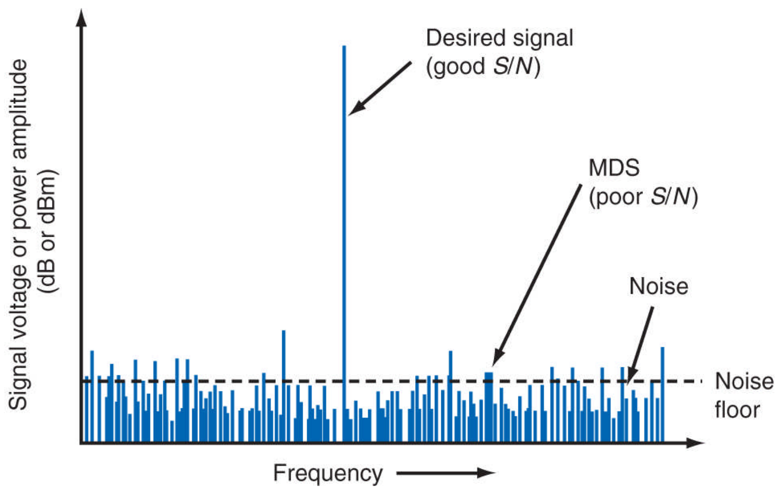


- Under-selective receiver suffers from increased external noise and interference from adjacent stations.



Sensitivity

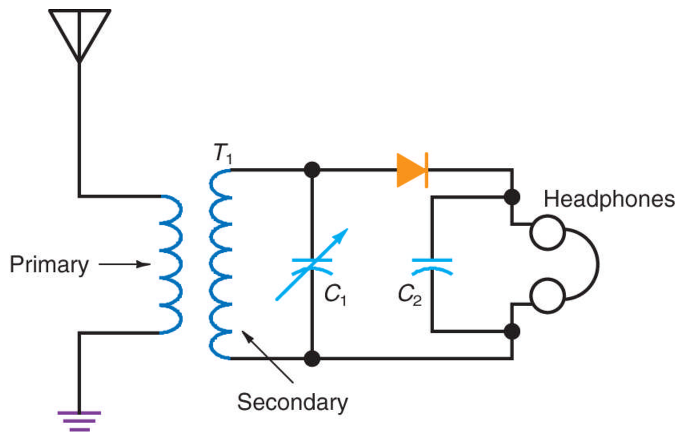
- **Sensitivity** refers to the weakest signal that can be received and still produce an acceptable out.
- Sensitivity can be specified as a minimum voltage (μV) or as a power level (dBm).
- A receiver's sensitivity is determined by its **gain** and also by its noise characteristic.



NAD C720BEE Stereo Receiver
FM sensitivity -103.9 dBm

Tuned radio receiver

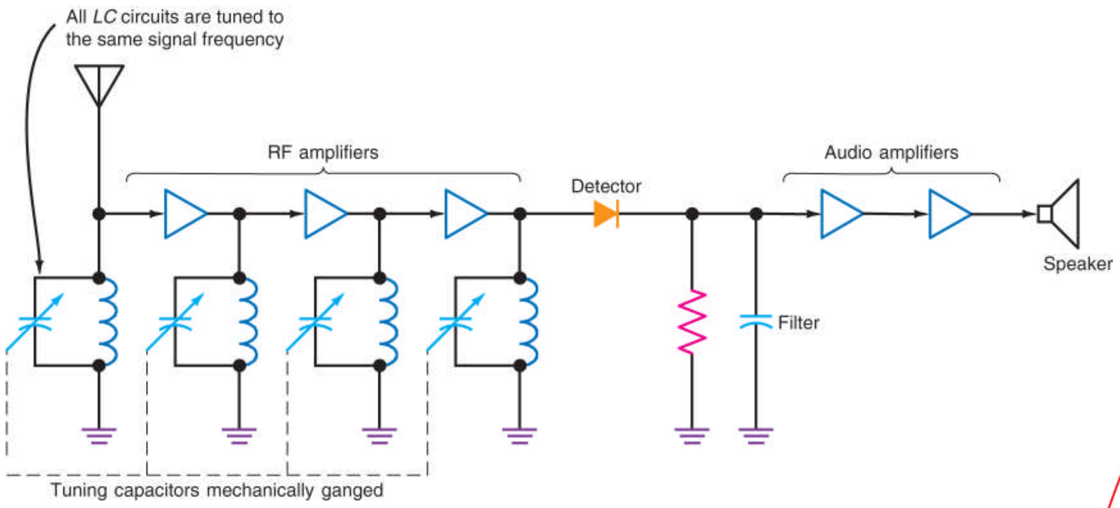
- The simplest of receivers, a “crystal radio,” consists of a tuned circuit, diode (crystal) detector and earphones.

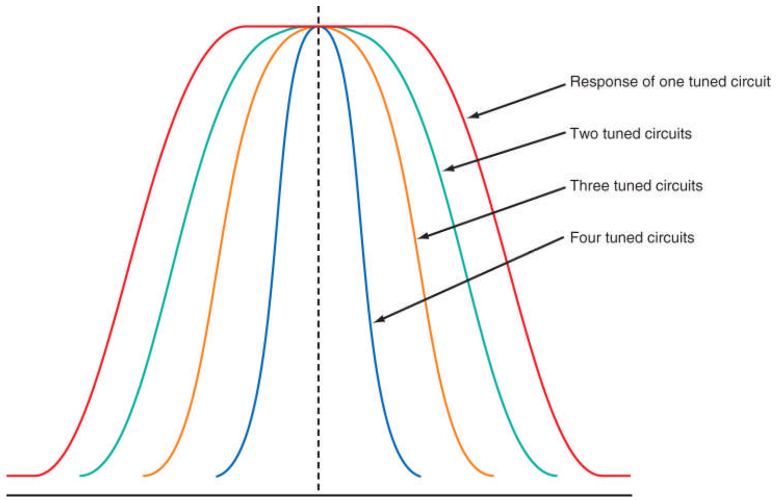


- Tuning is accomplished by adjusting a variable capacitor C_1 to change the resonant frequency.

Tuned radio receiver (TRF)

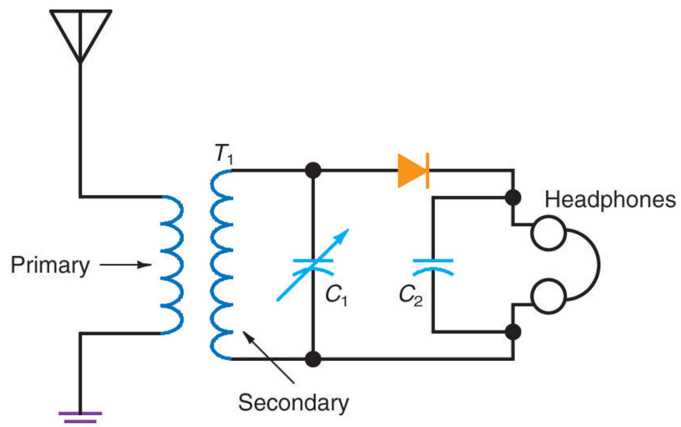
- In the TRF receiver below, selectivity is improved by cascading several RF amplifiers.





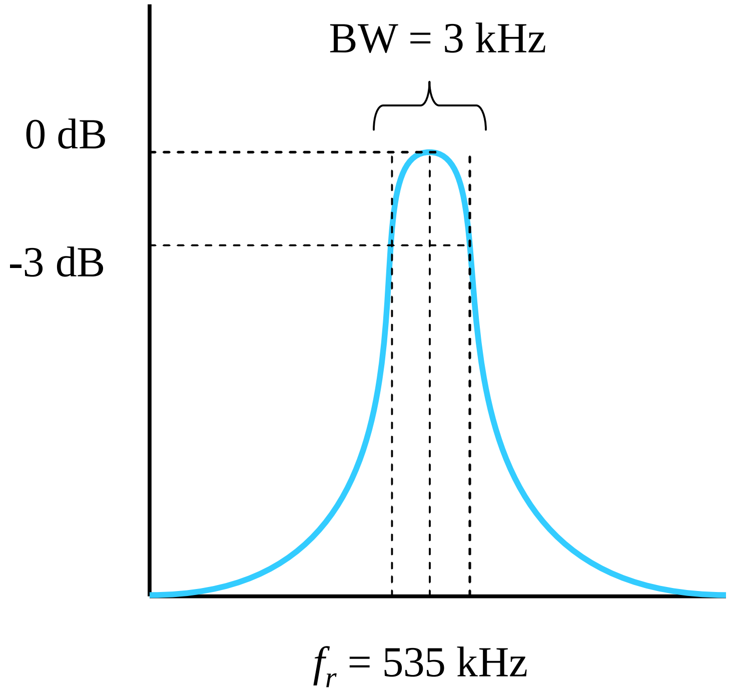
Example Problem 2

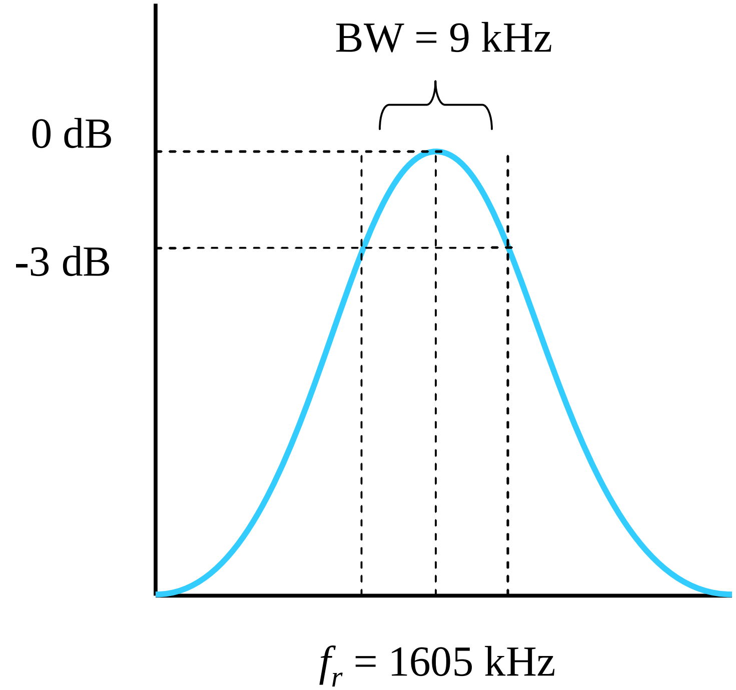
In the previous example, the bandpass filter had $Q = 178.3$ to provide a 6-kHz bandwidth at 1070 kHz. If Q remains a constant consider the filter selectivity at the ends of the dial (535 and 1605 kHz). For these two frequencies determine the resulting bandwidth.



TRF receiver problems

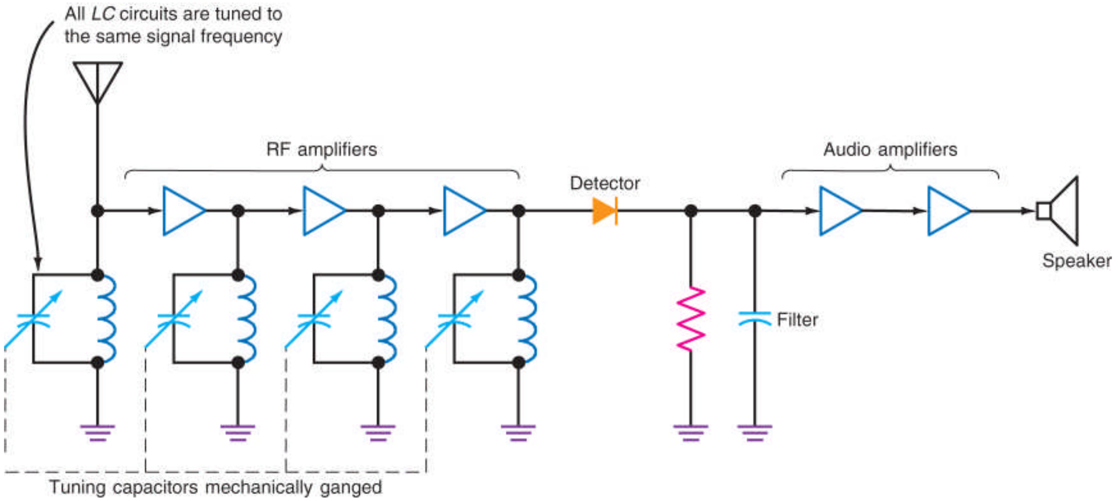
- The biggest problem with the TRF design is that selectivity varies with frequency.
  - The LC filter is too narrow at low frequencies and too wide at high frequencies.

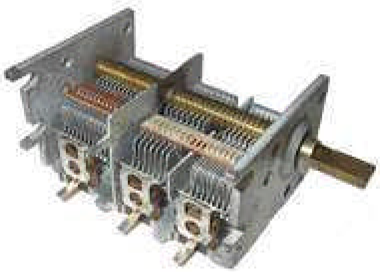




TRF receiver problems

- Another problem is in keeping all the stages of the RF amplifiers tuned to the exact same frequency.

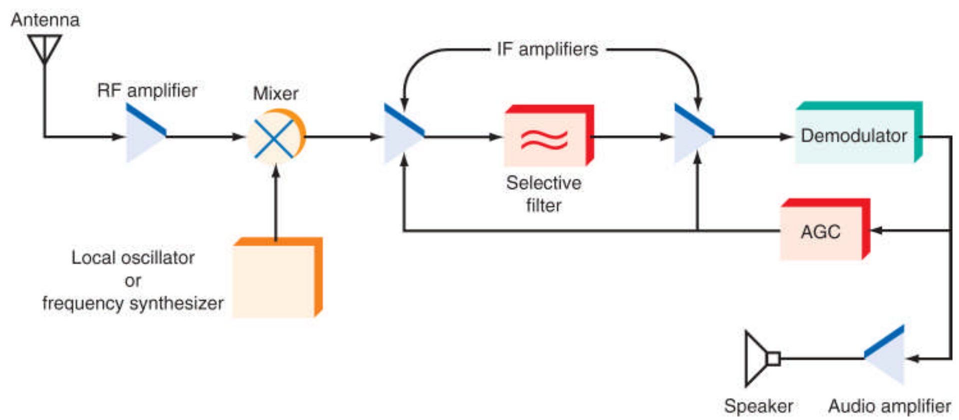




3 Gang variable capacitor

Superheterodyne receivers

- The shortcomings of the TRF receiver prompted the invention of the superheterodyne receiver.
- A superheterodyne receiver converts all incoming radio frequency (RF) signals to a lower frequency known as an intermediate frequency (IF).

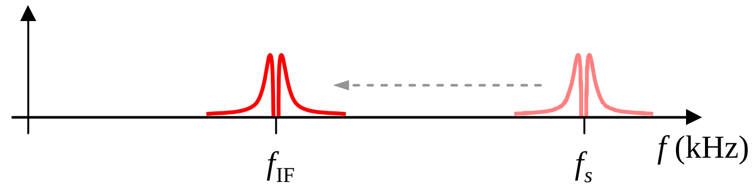


Frequency conversion

- Recall that in the transmitter, a mixer is used to translate a low frequency input to a higher frequency.
- The same process can be used in reverse by the receiver to translate an RF signal down to the IF.

RF signal

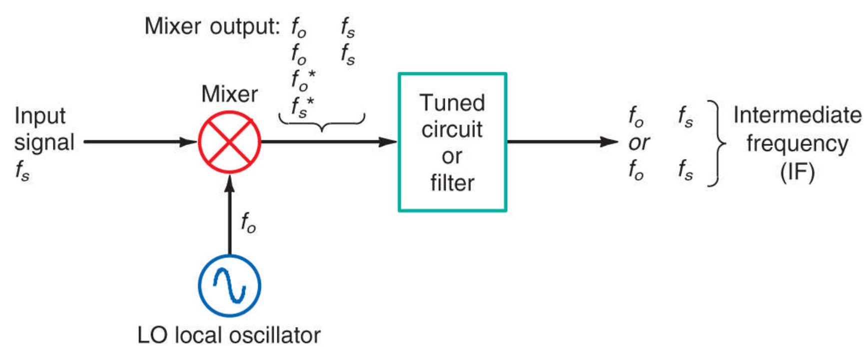
Down conversion to IF



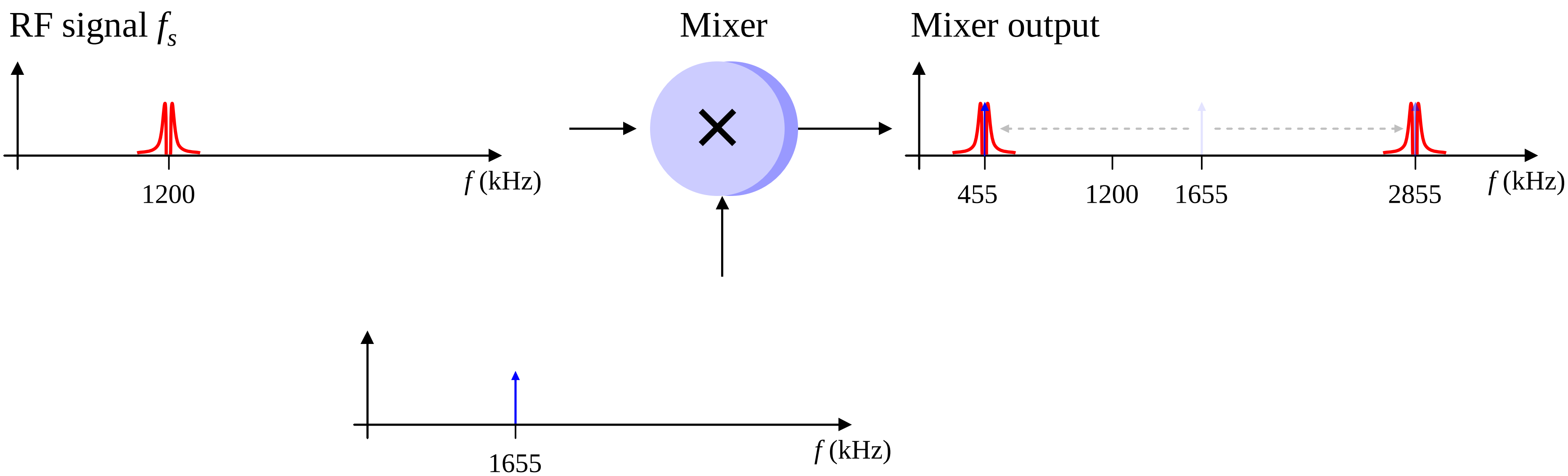
Mixing principles

- The inputs to the mixer are the radio signal f_s and a sine wave from a local oscillator f_o.
- The mixer output consists of four signals:
  - $f_o + f_s$
  - $f_o - f_s$ ← f_o is chosen such that f_o - f_s = f_{IF}
  - f_s
  - f_o

  (f_s and f_o:) f_o and f_s are artifacts of the mixer (we will ignore these)
- This function is called **heterodyning**.



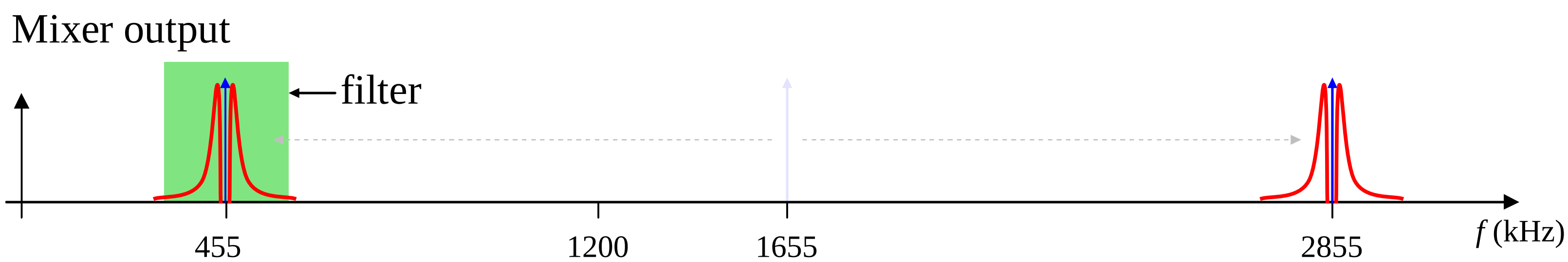
Mixing principles

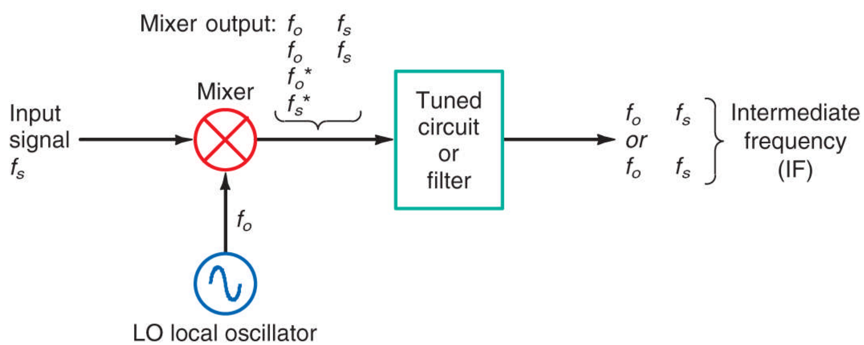


Receiver's local oscillator set at f_o = 1655-kHz

Selective filters

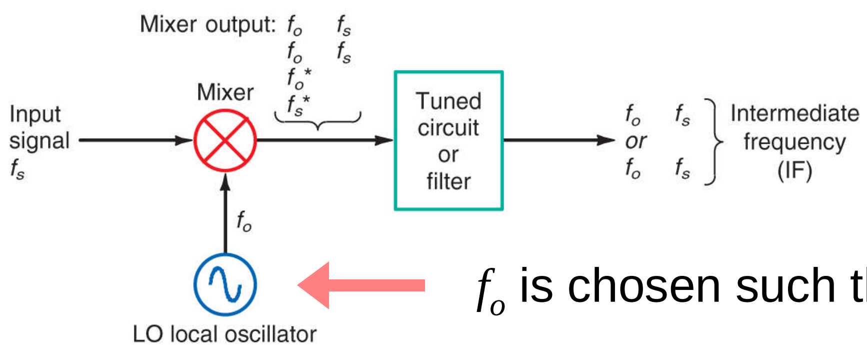
- The output of the mixer is filtered to eliminate everything but the IF signal.





Tuning a superhet receiver

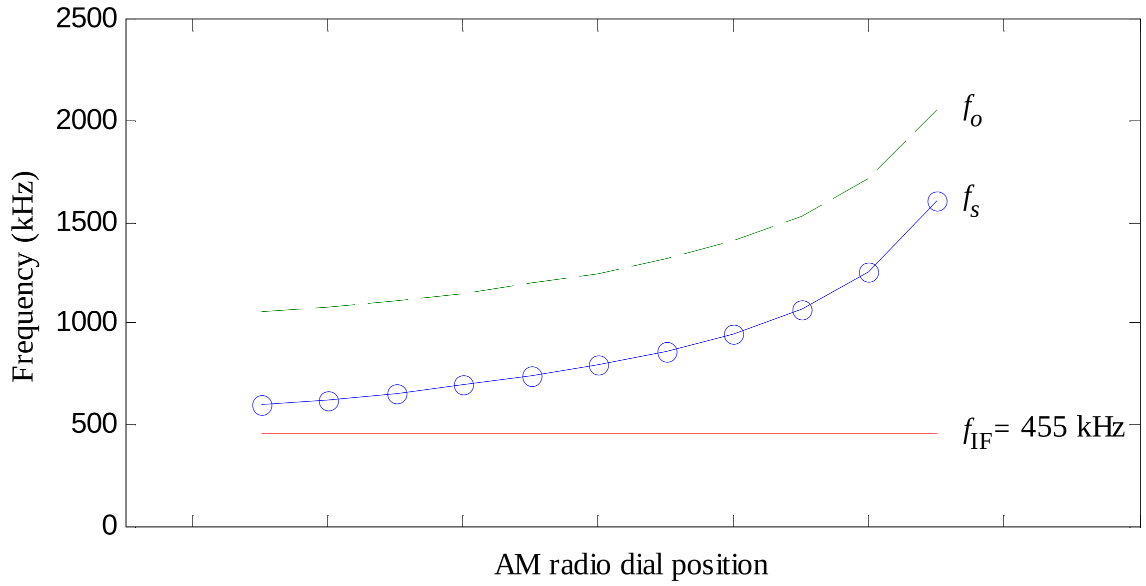
- In a TRF receiver, a station is tuned by adjusting the resonant frequency of a filter.
- In a superhet receiver, a station is tuned by changing the frequency of the receiver's local oscillator f_o.
  - The oscillator is set such that $f_o - f_s = f_{IF}$
  - f_{IF} is a fixed value (typically 455-kHz for AM radio).



f_o is chosen such that $f_o - f_s = f_{IF}$

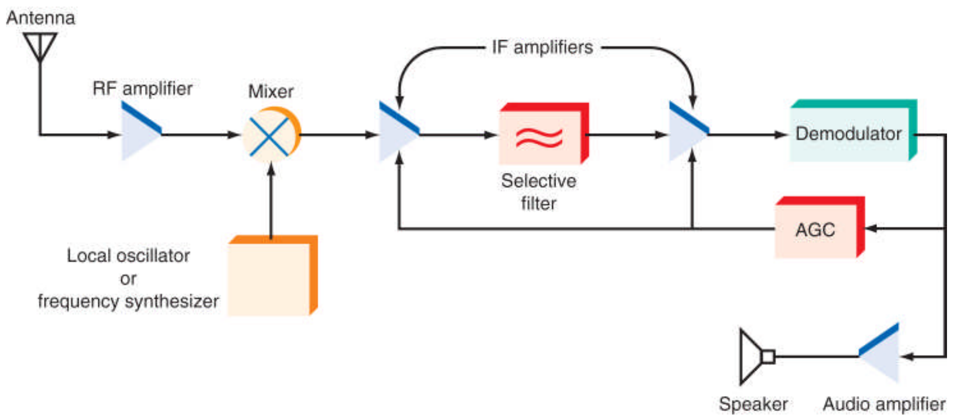
Local oscillator frequencies

- The local oscillator frequencies for low-side conversion are depicted below for broadcast AM.



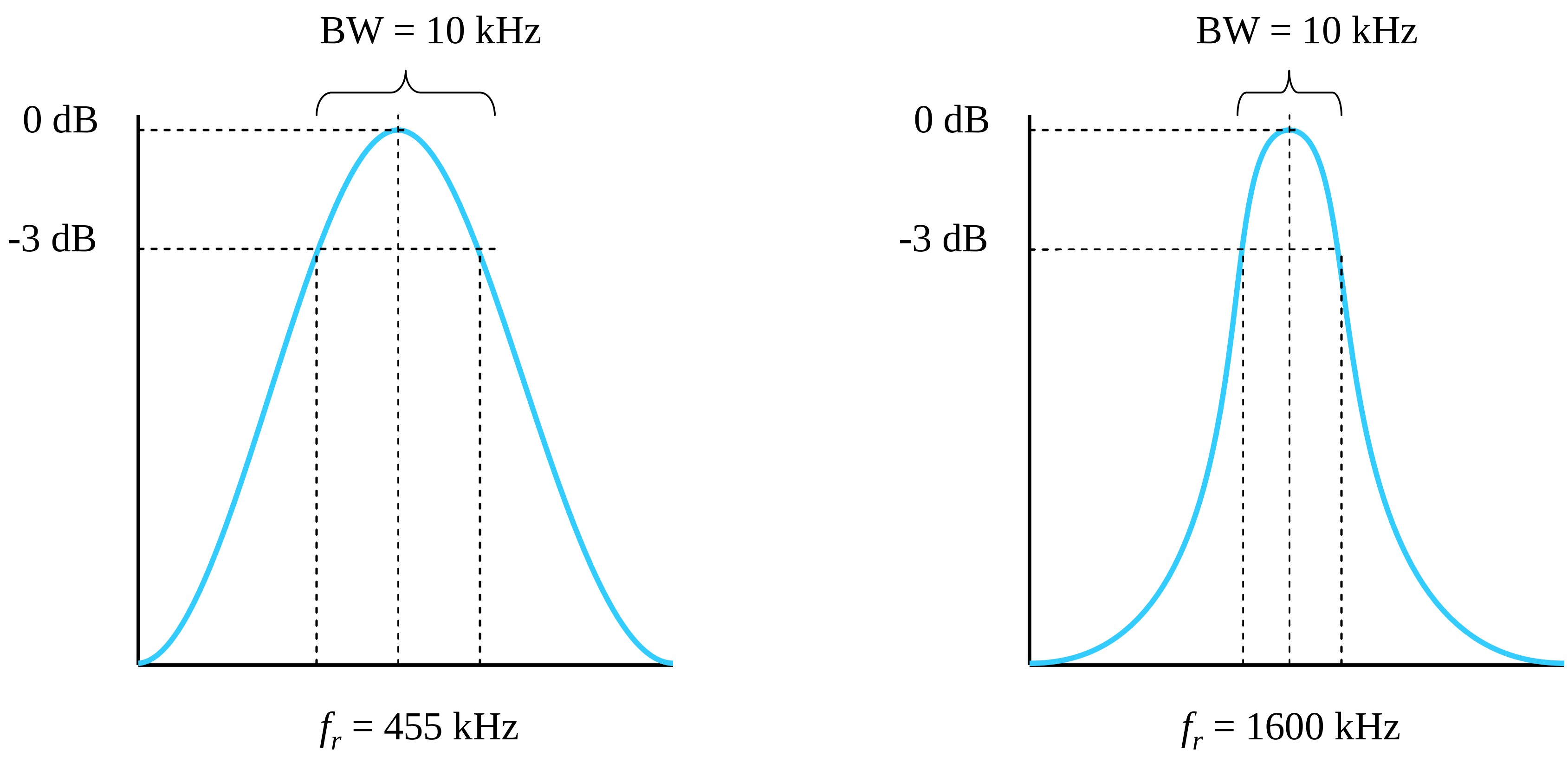
Superhet advantages

- TRF receivers suffered because changing the resonant frequency of the filter produced a changing filter bandwidth.
  - Selectivity varies with frequency.
- In superhet receivers, all the filtering (selectivity) occurs at a single, fixed intermediate frequency.



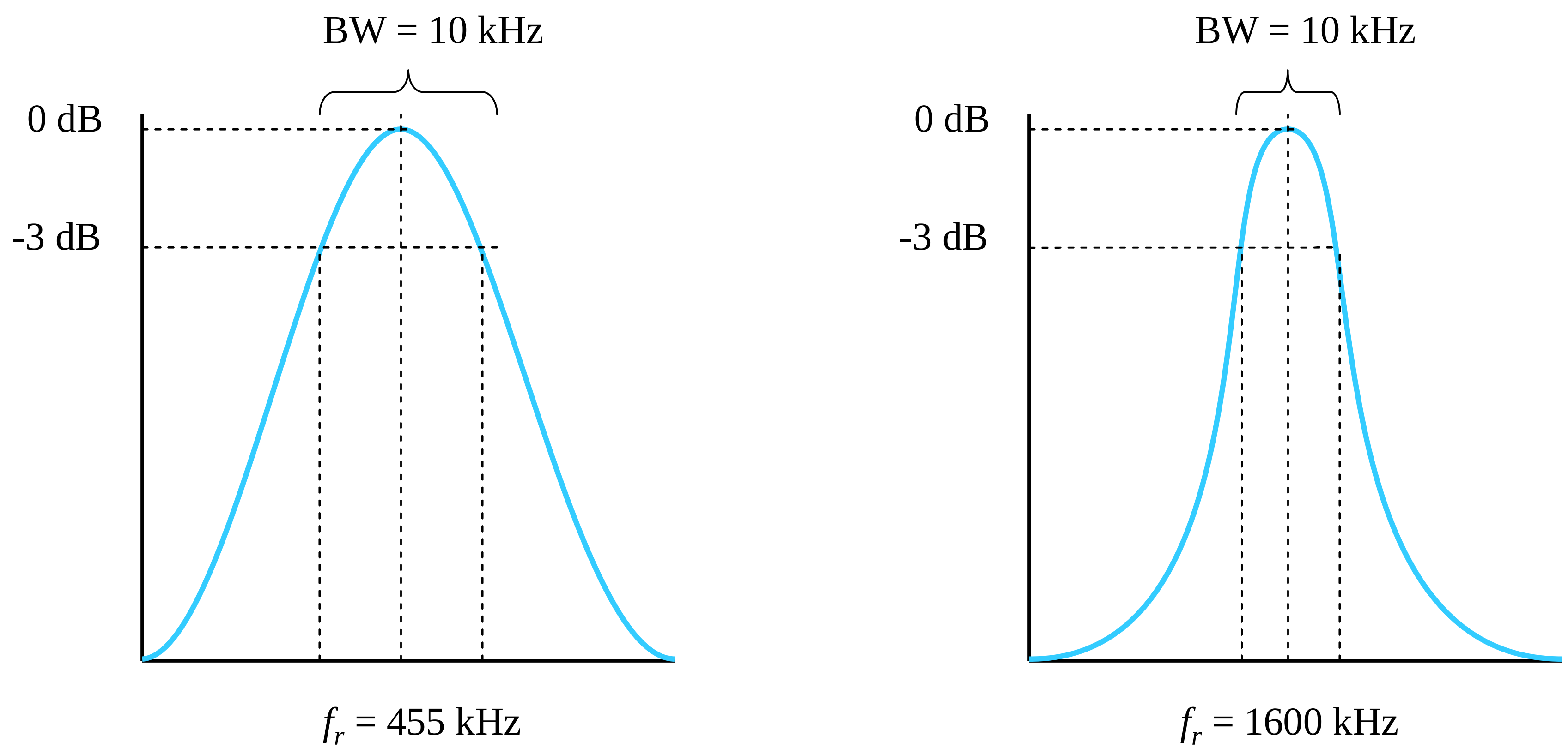
IF selectivity

- Since IF is typically a lower frequency than RF, it is easier to obtain a more selective IF filter.



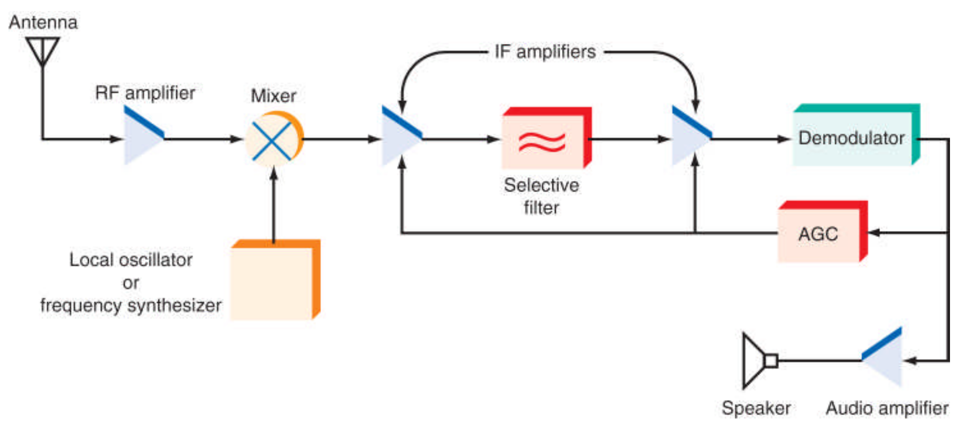
Example Problem 3

Determine the require value of Q for the two filters below.

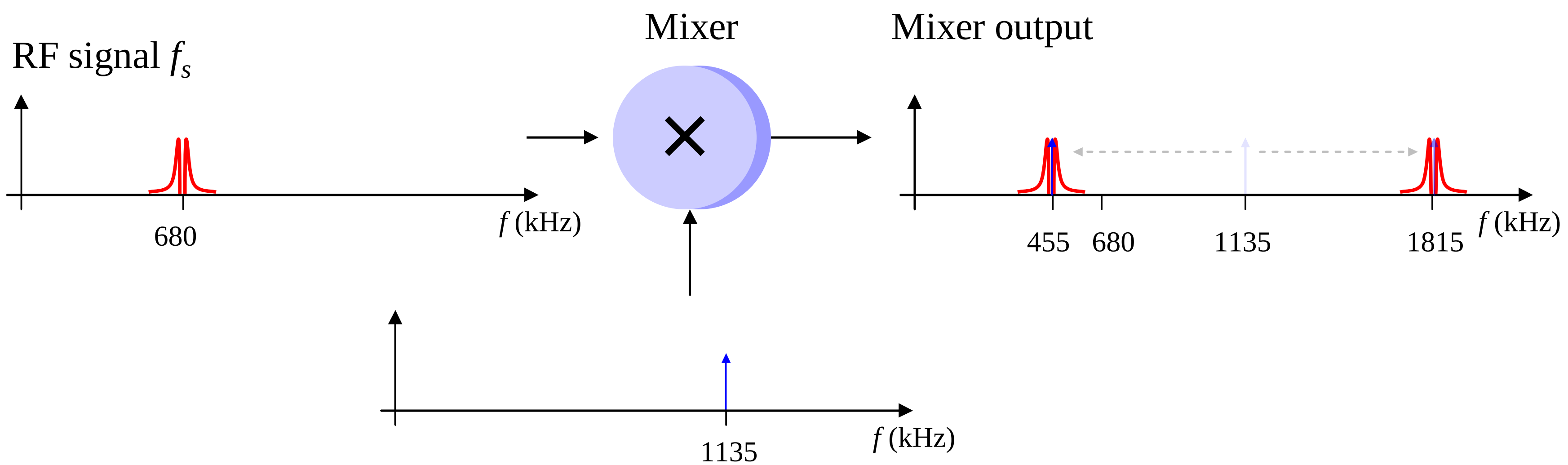


Example Problem 4

Suppose you wish to tune the AM station WCBM 680. To which frequency must the local oscillator in the receiver be tuned assuming an IF of 455-kHz? In addition to the IF, what other frequencies are present at the mixer's output?



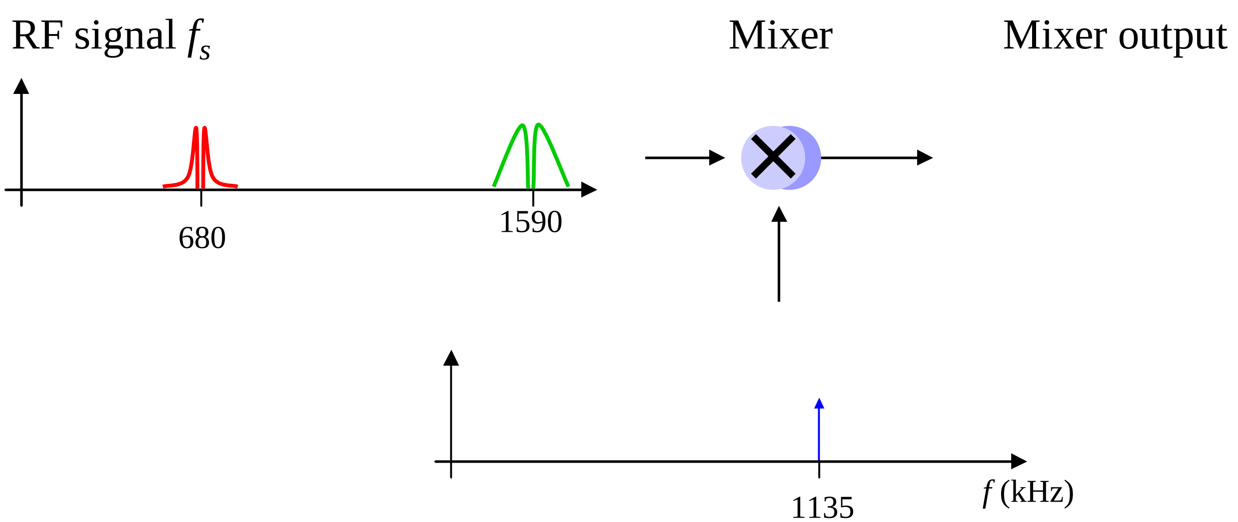
Example Problem 4



Receiver's local oscillator set at f_o = 1135-kHz

Example Problem 5

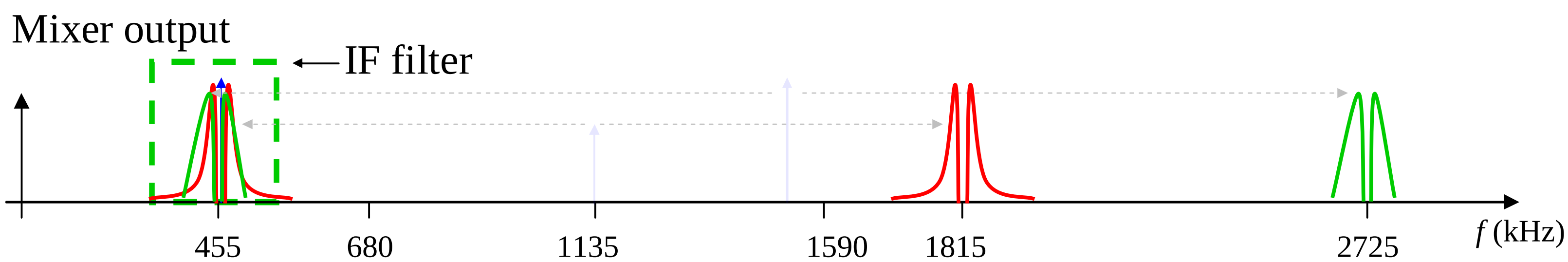
Suppose you tuned the AM station WCBM 680 with your local oscillator set to 1135-kHz. Now assume that in addition to the WCBM's signal, you are also receiving a broadcast station 1590-kHz (as depicted below). Sketch the frequencies present at the output of the mixer.



Receiver's local oscillator set at f_o = 1135-kHz

Image frequency

- The mixing process creates sum and difference frequencies for the desired signal (680 kHz).



- It also creates sum and difference frequencies for the undesired signal (1590 kHz).
  - The problem arises because the difference frequencies are the same (both 455 kHz)

$$1135 - 580 = 455 \text{ kHz}$$

$$1590 - 1135 = 455 \text{ kHz}$$

Image frequency

- The image frequency f_i is a potentially interfering RF signal that is spaced 2 times the IF above or below the desired frequency f_s.

$$f_i = f_s + 2 f_{\mathrm{IF}} \quad \text{and} \quad f_i = f_s - 2 f_{\mathrm{IF}}$$

- Which image that occurs depends upon whether the local oscillator frequency f_o is above or below the signal frequency.

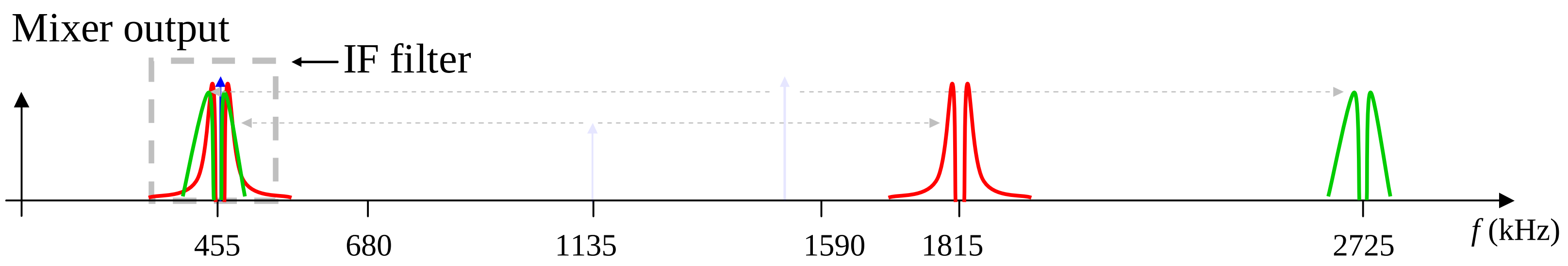
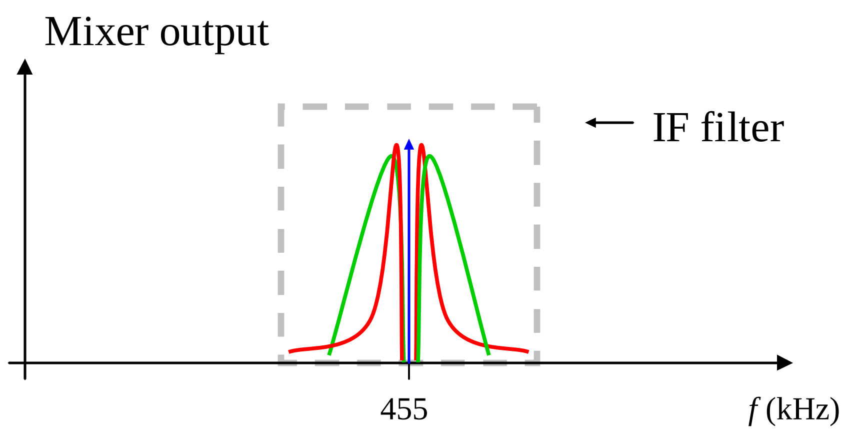


Image frequency

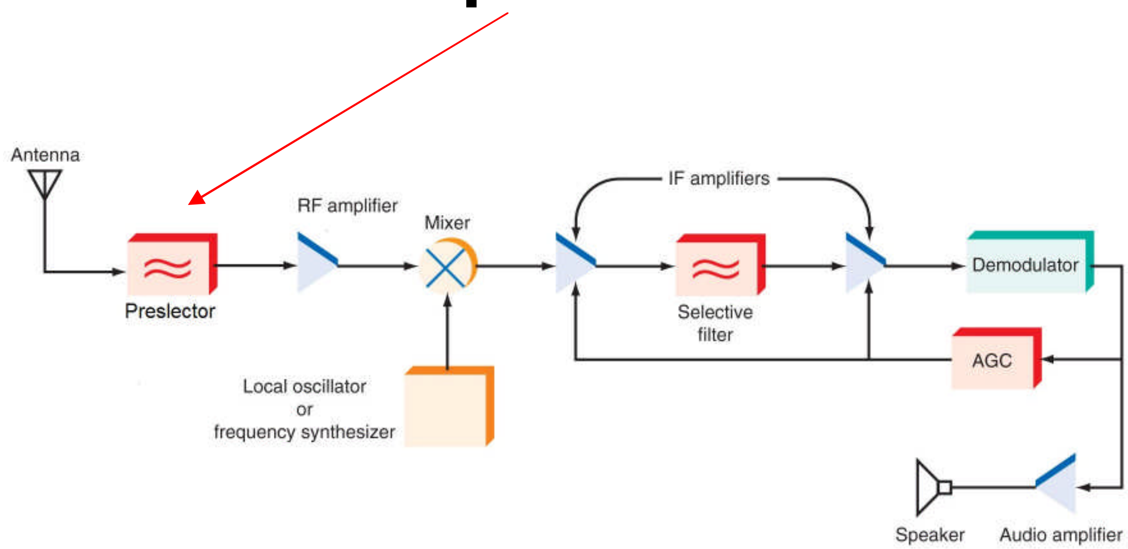
- Once the image signal is mixed down to the IF, there is no way to separate the desired signal from the undesired.



- How can we solve the problem of images?

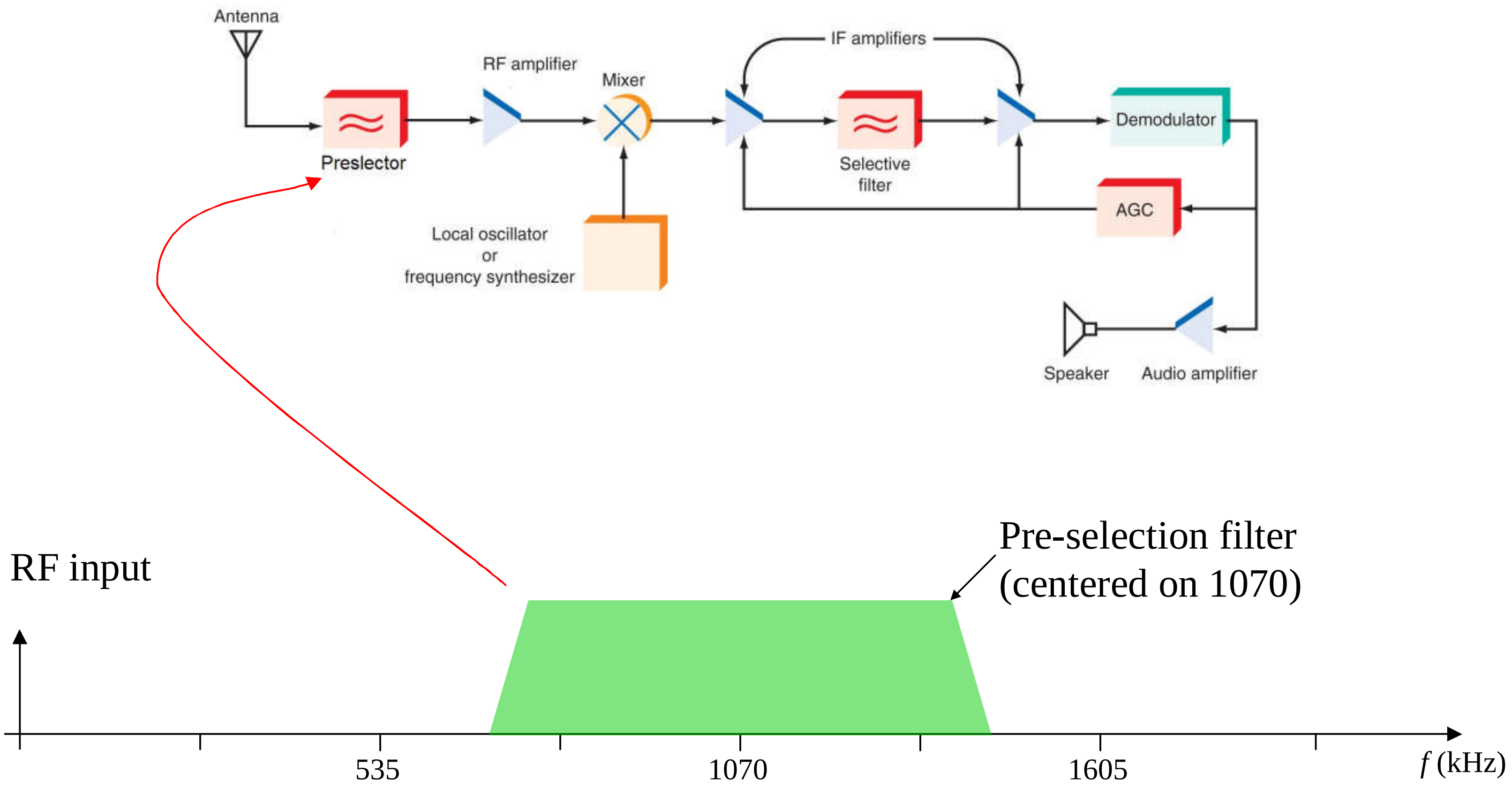
Image frequency

- In order to prevent interference, we need to prevent the image frequency from appearing at the mixer.
- This is accomplished by the use of bandpass filter associated with the initial RF amplifier sometimes called a **preselector**.



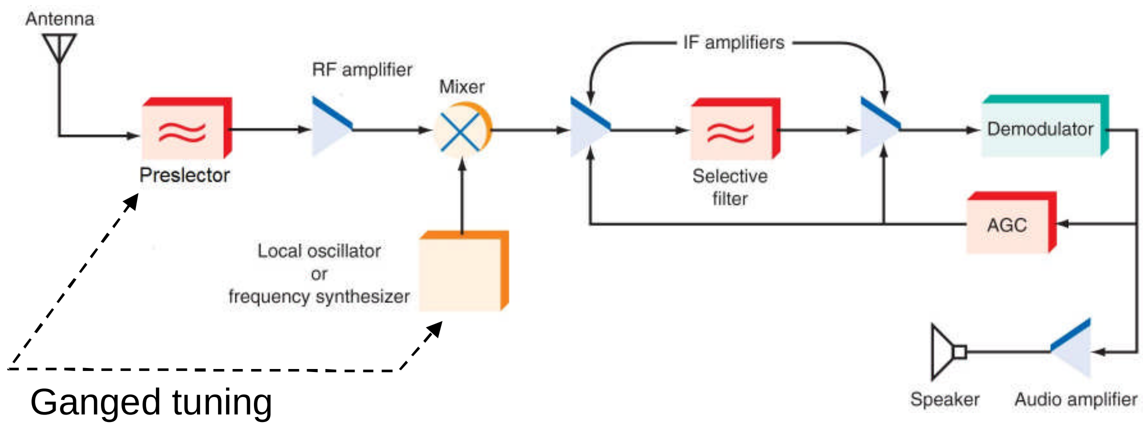
Preselector

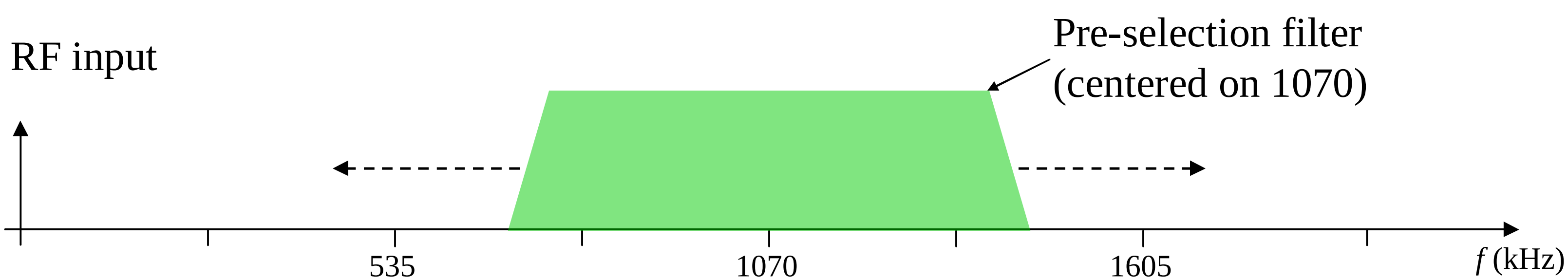
- The purpose of the preselector is to filter out any potential image frequencies prior to the mixer.



Preselector

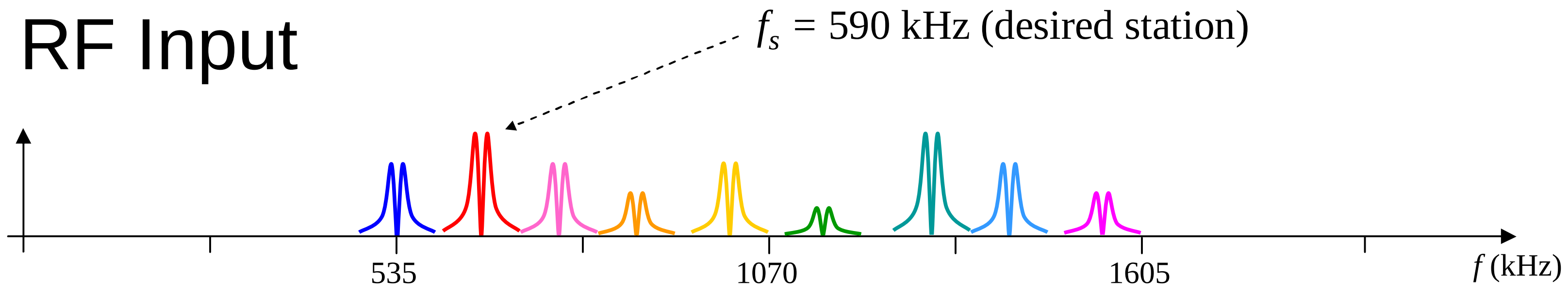
- The preselector is a broad-tuned bandpass filter with an adjustable center frequency that is tuned to the desired carrier.



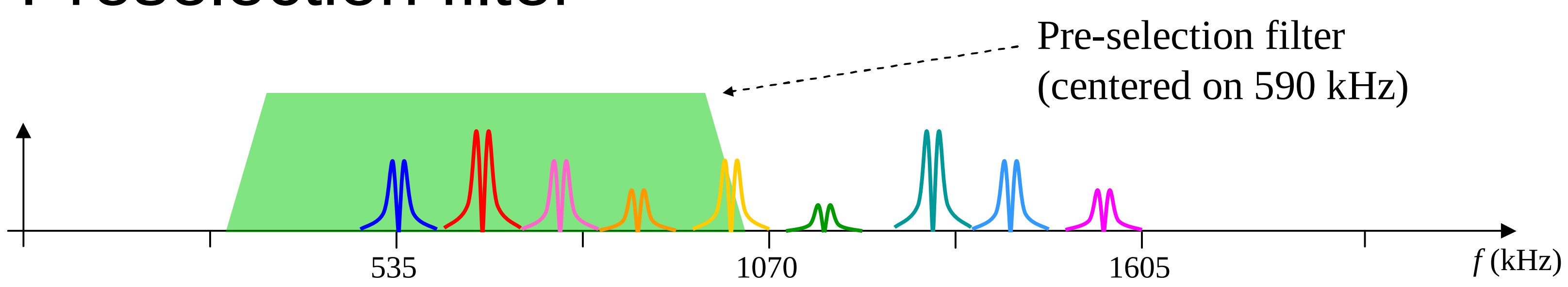


Preselector operation

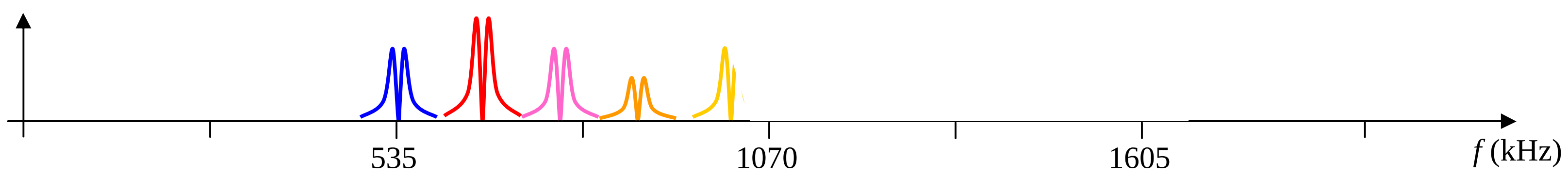
- RF Input



- Preselection filter

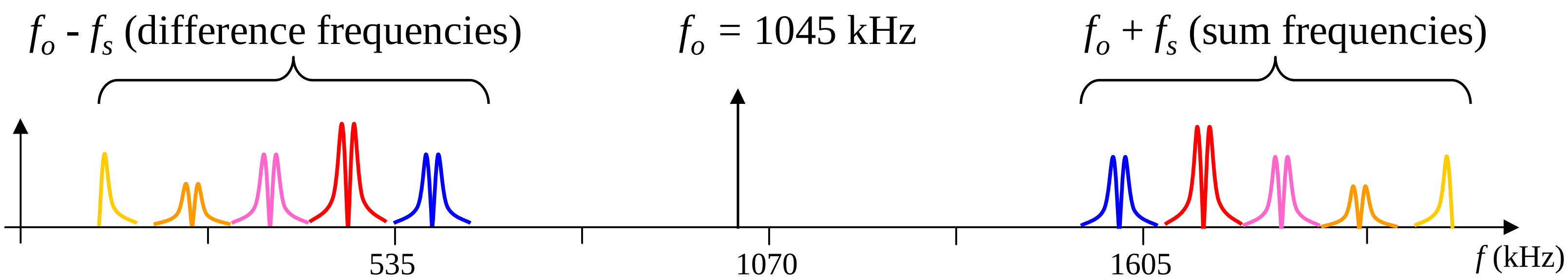


- Output of preselector (input to mixer)

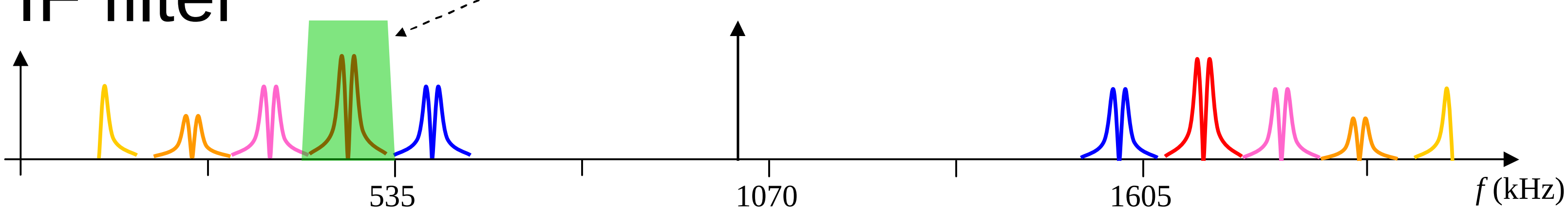


Mixer and IF filter operation

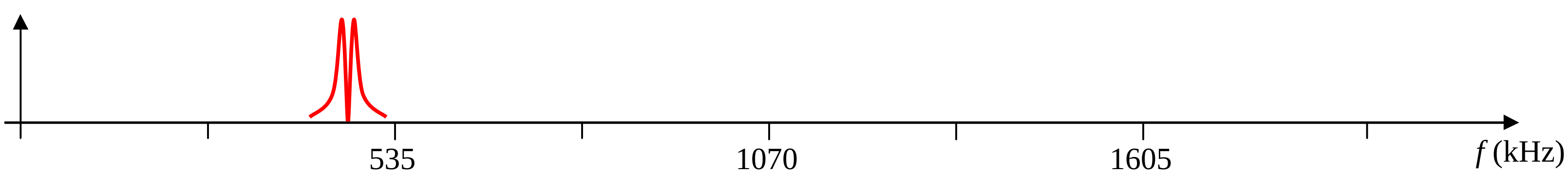
- If f_s = 590-kHz then f_o = 1045-kHz, after the mixer



- IF filter



- Output of IF filter (input to demodulator)



Other common IF values

- The selection of the IF depends upon the frequency bands covered by the receiver.
- Below are some common IF values
  - Broadcast AM 455-kHz
  - Broadcast FM 10.7-MHz
  - TV 40 – 50 MHz

Example Problem 6

Consider tuning a superheterodyne receiver to 90 MHz in the FM spectrum depicted below. The IF for this FM receiver is 10.7 MHz and the preselector response is depicted. To which frequency does the local oscillator f_o need to be set? Sketch the frequency domain present at each stage in the receiver (B C D)